Boston Architectural Center

Architect Registration Exam Review

Subject:	Lateral Loads
Date:	Friday June 18th
Time:	11:00 am to 2:00 pm
Instructor:	Garen B. Gregorian, PE, MSCE, MSME Gregorian Engineers
Purpose:	To refresh knowledge of the subject

Introduction:

- Lateral Loads

- Earthquake Loads

Analysis of Earthquake loading:

Dynamic Method - Introduction
Equivalent Static Method

- Wind Loads

Earthquakes:

- Causes of Earthquakes, Magnitude, Terminology
- Measurement of earthquake response for design
- Response Spectrum – response coefficient
- Design Spectrum – response design coefficient

Faults and Seismic Waves:

- Caused by Slipping of adjacent plates of the earths crust and subsequent release of energy
- Seismology and plate tectonics. Study of Plate Movement, Friction, and Release of Energy.
- Three types of waves are generated during earthquakes.
- P (Normal, Pressure, or Compression) waves, S (Shear waves), Surface (Love or Raleigh) waves.
- Shear waves have highest velocity and cause most damage.

Magnitude of Earthquakes:

- Richter Scale: Measure of released energy based on instrument recordings.

  Each scale number approximately equals 32 times the amount of energy release than the prior scale number.

- Modified Mercalli Intensity Scale: Rating based on observed damage to structures, which is subjective.

  Scale range: I to XII
  Rating is imprecise and includes verbal description of damage

- Neither used in Design.

- Strong Motion Accelerograph machine measures acceleration of ground or a building.

Terminology:

- **Hypocenter**: Location below surface of the earth where earthquake energy is released.

- **Epicenter**: Location on the earth surface directly above the epicenter.

- **Isoseismal Curves**: Curves of equal earthquake magnitude

- **Hypocentral Distance**: Distance from measuring station to the rupture zone below the earth surface.

- **Epicentral distance**: Distance on the surface of the earth from the measuring station to the epicenter.

- **Rupture Surface**: Area on the earth surface where rupture is observed due to earthquake.

F = M . a

- Newton's Second Law of Motion

- Force equals Mass times Acceleration

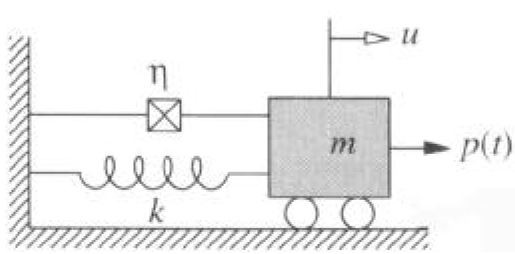
- $V = C_a . W$ (Percentage of weight of Building)

V = Base shear force
C_a = Seismic Response Coefficient (%g)
W = Effective Weight of Structure
(Dead Load + Partition Load + Weight of Permanent Equipment +20% Snow Load

- m . u" + c . u' + k . u = f (t)
  c= damping coefficient
  k= spring or stiffness constant (F = k . x)

Single Degree Linear Oscillator:

- m . u" + c . u' + k . u = f (t)
  c= damping coefficient
  k= spring or stiffness constant (F = k . x)
- Period: Time for one complete oscillation. [sec]
- Frequency: The number of oscillations in one second. [1/sec]
- Characteristic or Natural Frequency of system. Depends on the properties of the structure. Namely Mass and Stiffness. $w_0 = (k/m)^{1/2}$
- Driving Frequency of the system. Depends on the natural frequency of the soil. (i.e.; clay (low frequency) or rock (high frequency)) Or natural frequency of the wind.
- Vibration Control of a given system.
  a) Varying Natural Frequency
  b) Introducing Damping
  c) Vibration Isolation
  d) Tuned Damper –Vibration Neutralizer



Rigidity and flexibility:

Rigid structures take more load than flexible ones, yet we don't want too flexible a structure.
Depending on the natural frequency of the soil or forcing frequency, the building should be designed to avoid soil structure resonance.

Earthquake Response Spectrum.

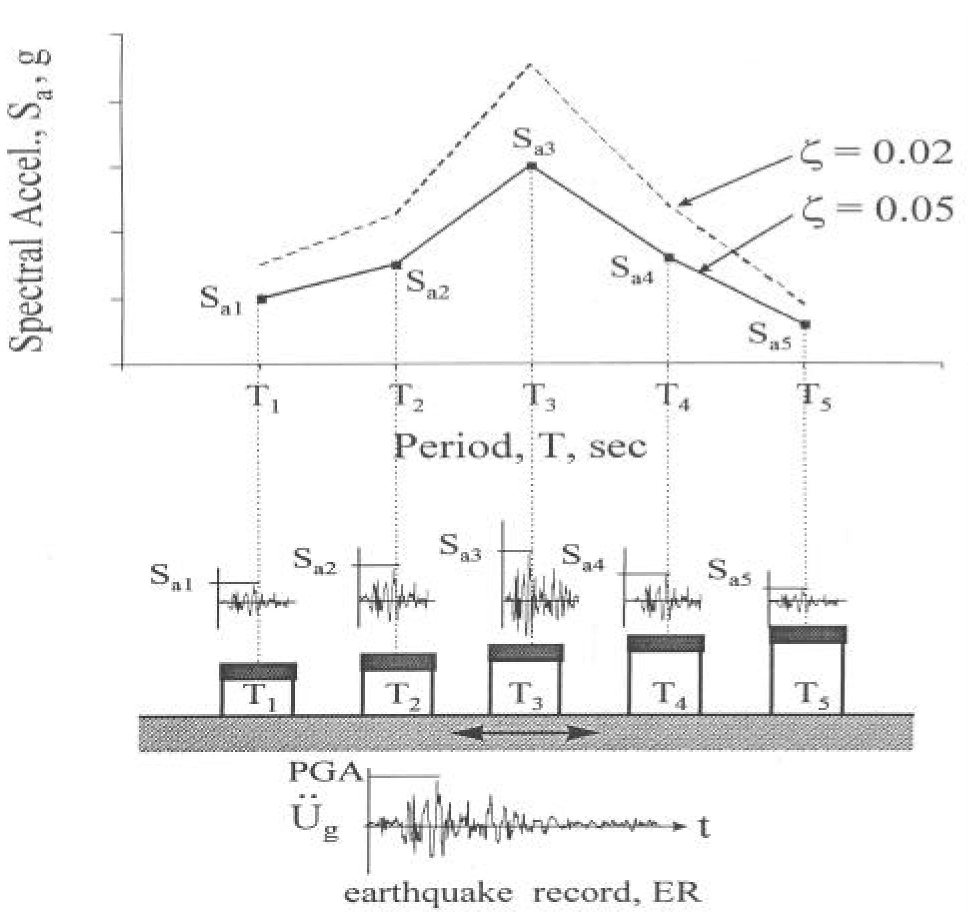
Pendulums of varying period are placed on a shaking table.

Strong motion earthquake is introduced at the base of the shaking table.

The maximum response (displacement, velocity, acceleration) of the pendulums is recorded and plotted.

Response spectrum is the response measured due to a specific earthquake for systems with wide range of periods.

Response spectrum can only be used for a specific earthquake.



Equivalent Static Load Method:

Determine the Base Shear, V, Total Lateral Force at base of structure:

$F = \%g \,.\, W$ $(F = m \,.\, a)$

$V = (C_v \,.\, I / R \,.\, T) \,.\, W$

$(0.11\ C_a \,.\, I) \,.\, W < V < (2.5 \,.\, C_a \,.\, I / R) \,.\, W$

I, C_v , C_a, Z and R factors:

I: Importance Factor, based on occupancy category

C_v , C_a : Seismic Coefficients measures of the expected ground acceleration at the site. Depend on seismicity of a region and the soil characteristics

Z: Seismic Zone Factor, seismic risk present at a give site

R: Response Modification Factor Reflects the energy absorbing capability of a structural system. Measure of ductility and overstrength factor

Fundamental Period of the Building:

Determined by analysis or empirical approximate methods.

Approximate method:

$T = C_t\ (h_n)^{3/4}$

C_t = 0.035 for moment resisting steel frames
= 0.030 for reinforced concrete moment resisting frames
= 0.030 for eccentric braced frames
= 0.020 for all other buildings

h_n = Height of structure

Steps in finding the Base Shear:

Step-1: Determine Seismic Zone Factor (1, 2, 2A, etc.)
Step-2: Determine Soil Profile S (A, B, C, etc.)
Step-3: Determine Period T of the building $T = C_t (h_n)^{3/4}$
Step-4: Determine Importance Factor - I
Step-5: Determine Cv, and Ca
Step-6: Calculate $V = (C_v . I / R . T) . W$

$$(0.11\ C_a . I) . W < V < (2.5 . C_a . I / R) . W$$

Limitations: Used for regular buildings less than 240 feet high.
Irregular buildings less than 65 feet high.

Distribution of Base Shear:

Shear is distributed in a uniform triangular form from zero at the base to a maximum at the top:

Additional force at top for T>0.7 (Whip Effect)
$F_t = 0.07\ T . V < 0.25\ V$

The total lateral load due to earthquake ($V-F_t$) is then distributed along the height of the building according to weight of the story and the height at which it is:

$F_x = (V-F_t) . w_x . h_x /$ Ó $w_i . H_i$

Ó $w_i . h_i$ = Sum of all floor weights times their heights at floor under consideration

Limitations: Uniform mass distribution and equal floor heights.

Other methods of distribution are allowed based on assumed deflected shape of the building structure.

Lateral Loads Structural Vocabulary:

Earthquake Design:

Base shear: is the total design lateral force or shear at the base of the structure.

Bearing wall system: A Structural system without complete vertical load carrying space frame.

Boundary Element: Is an element at edges of openings or at perimeters of shear walls or diaphragms.

Braced Frame: is an essentially vertical truss system of the concentric or eccentric type that is provided to resist lateral forces.

Building Frame system: is an essentially complete space frame that provides support for gravity loads.

Cantilevered Column Element: is a column element in a lateral force resisting system that cantilevers from a fixed base and has minimal moment capacity at the top, with lateral forces applied essentially at the top.

Collector: is a member or element provided to transfer lateral forces from a portion of a structure to vertical elements of the lateral force resisting system.

Component: is a part or element of an architectural electrical mechanical or structural system.

Component, Flexible: is a component having a fundamental period greater than 0.06 second.

Component, Rigid: is a component having a fundamental period less than 0.06 second.

Concentrically braced frame: is a braced frame in which the members are subjected primarily to axial forces.

Design basis ground motion: is that ground motion that has a 10 percent chance of being exceeded in 50 years as determined by a site specific hazard analysis or may be determined from a hazard map.

Design Response Spectrum: is an elastic response spectrum for 5 percent damping used to represent the dynamic effects of the design basis ground motion for the design of structures.

Design Seismic Force: is the minimum total strength design base shear factored and distributed to the building.

Diaphragm: is a horizontal or nearly horizontal system acting to transmit lateral forces to the vertical resisting elements. The term Diaphragm includes horizontal bracing systems.

Diaphragm Chord/ Shear Wall Chord: is the boundary element of the diaphragm or shear wall that is assumed to take axial stresses analogous to the flanges of a beam.

Diaphragm Strut (drag strut, tie, collector): is the element of a diaphragm parallel to the applied load that collects and transfers diaphragm shear to the vertical resisting elements or distributes loads within the diaphragm. Such members may take axial tension or compression.

Drift: Lateral displacement

Dual system: is a combination of moment resisting frames and shear walls or braced shear walls or braced frames.

Eccentrically Braced Frame (EBF): lateral load resisting braced frame where the diagonals of the brace do not meet at the beam to column joint.

Lateral Force Resisting System: is that part of the structural system designed to resist the design seismic or wind loads.

Moment Resisting Frame: is a frame in which members and joints are capable of resisting forces primarily by flexure.

Moment Resisting Wall Frame (MRWF): is a masonry wall frame especially detailed to provide ductile behavior.

Ordinary Moment Resisting Frame: is a moment resisting frame not meeting special detailing requirements for ductile behavior.

Orthogonal Effects: are the earthquake load effects on structural elements common to the lateral force resisting systems along two orthogonal axes.

P Delta Effect: is the secondary effect on shears, axial forces and moments of frame members induced by the vertical loads acting on the laterally displaced building system.

Shear Wall: is a wall designed to resist lateral forces parallel to the plane of the wall.

Soft Story: is one in which the lateral stiffness is less than 70% of the stiffness of the story above.

Soil Structure Resonance: is the coincidence of the natural period of a structure with a dominant frequency of the ground motion.

Space Frame: is a three dimensional structural system, without bearing walls, composed of members interconnected so as to function as a complete self contained unit with or without the aid of horizontal diaphragms or floor bracing systems.

Special Concentrically Braced Frame (SCBF): is a concentrically braced frame designed and detailed to provide ductile behavior.

Special Moment Resisting Frame (SMRF): is a moment resisting frame specially detailed to provide ductile behavior.

Story Drift: is the lateral displacement of one level relative to the level above or below.

Story Shear: is the summation of the design lateral forces above the story under consideration.

Wind Design:

Law of Conservation of Momentum:

$F = m \cdot dv/dt$
Neglecting Potential Energy Bernoulli Equation :

$P + \frac{1}{2} \cdot \rho \cdot V^2$ = Constant (Total Energy of System)

P = Static Pressure (relative velocity between elements = 0)
$\frac{1}{2} \cdot \rho \cdot V^2$ = Dynamic Pressure (kinetic energy)
ρ = Density of fluid (air)

When body is placed along path of a moving fluid:

$P + \frac{1}{2} \cdot \rho \cdot V^2 = P_\infty + \frac{1}{2} \cdot \rho_\infty \cdot V_\infty^2$
P_∞ = Static pressure of undisturbed free stream (found in tables)
Assume relative velocity of finite elements = 0
V_∞ = Free stream velocity
V = Local velocity
P = Local pressure

Stagnation Point: As air molecules due to wind strike a buildings surface, the local velocity approaches zero at the stagnation point.

At stagnation point where the local velocity (v) is zero:

$P = P_\infty + \frac{1}{2} . \rho_\infty . V_\infty^2$ or $Cp = P - P_\infty / \frac{1}{2} . \rho_\infty . V_\infty^2 = 1$

Cp = Pressure coefficient

Prominent corner or Salient Corner: A location at the extreme edges of the building where wind becomes very turbulent.

Internal Pressure: The air pressure within a building may be higher or lower than air pressure outside because of heating cooling or ventilation.

Partially open structures: A structure is more likely to catch wind and experience a ballooning effect within the structure.

Fastest Mile wind: Average speed of a column of air one mile long passing over a point.

Extreme Fastest Mile Wind: Highest fastest mile wind speed recorded in certain time period. 50 year time period for example.

Basic Wind Speed:

Region	Wind Speed (mph)
Continental regions more than 100 miles from coast	45 - 100
Islands and coastal regions exposed to tropical storms	135 - 180
Islands and coastal regions exposed to subtropical storms	90 – 135
Islands and coastal regions NOT exposed to subtropical storms	70 - 90
Tornado Prone Regions	90 - 160

Wind Exposure Category: Wind pressure is dependant on the terrain

Category A: City
Category B: Suburban areas
Category C: Open Lands
Category D: Open bodies of water

Wind stagnation pressure at height of 33 feet							
Basic wind Speed (mph)	70	80	90	100	110	120	130
Pressure qs (psf)	12.6	16.4	20.8	25.6	31.0	36.9	43.3

Design Wind Pressure:

$P = q_s \times C_e \times C_q \times I_w$

P = Design Wind Pressure
q_s = Wind Stagnation Pressure = 0.00256 . V^2 at 33 feet height.
C_e = Combined Height Exposure and Gust Factor
C_q = Pressure coefficient for portions of structures, Windward, Leeward, Roof, etc.
I_w = Importance Factor

Steps in determining Design Wind Pressure:

Step-1: Determine Basic Wind Speed
Step-2: Determine Pressure coefficient q_s
Step-3: Determine C_e From Table
Step-4: Determine C_q From Table
Step-5: Determine I_w

Step-6: $P = q_s \times C_e \times C_q \times I_w$

Limitation: Structures less than 400 feet in height.
No dynamic effects considered
(height to width ratio less than 5)
Wind tunnel testing required for buildings sensitive to wind induced oscillations.

IBC 2000 Provisions:
(International Building Code 2000)

Maximum Considered Earthquake: The most severe earthquake effect considered by code.

Seismic Performance Category: Includes Seismicity at the site and Occupancy of the structure.

SPC A, B, C, D, & E Roughly equivalent to Seismic Zones 0, 1, 2, 3 & 4

Seismic Use Group:

I - All other structures not in use group II, and III.
II – Substantial Public Hazard.
III – Essential Facilities

Site Class: (Used to be S1 thru S4) Now is Class A, B, C, D, E, & F
Based on:

Shear wave velocity Vs
Standard Penetration Resistance or Blow Count
Undrained Shear Strength Su

Mapped Maximum Considered Earthquake Spectral Response Accelerations for short (Ss, 0.2 sec) and long periods (S1, 1 sec)

Ss = MCE Spectral Response Acceleration Short Period (Acceleration Dependant region)

S1 = MCE Spectral Response Acceleration Long Period (Velocity Dependant Region)

Can obtain Ss, and S1 from USGS CD-Rom

Fa = Site coefficient Short period Acceleration Dependant
Fv = Site coefficient Long Period Velocity Dependant

Site specific Dynamic procedure: Use site specific design spectrum. (not covered in ARE)

General Procedure: Equivalent static load method

1. Find/Determine Ss, S1
2. Determine Site Coefficients (Soil Modification Factors) Fa, and Fv from Tables.
3. Calculate Soil Modified MCE spectral response acceleration at short and long periods S_{MS} and S_{M1}
   S_{MS} = Fa x Ss
   S_{M1} = Fv x S1
4. Calculate short and long period Design Spectral Response Acceleration: S_{DS} , S_{D1} – 2/3 is the factor of safety that is been built into seismic design model codes of the recent past.
   S_{DS} = 2/3 x S_{MS}
   S_{D1} = 2/3 x S_{M1}
5. Calculate C_s: $S_{DS}/(R/I_E)$

$0.044S_{DS}\ I_E < C_s < S_{DS}/(R/I_E)$

R = Response Modification Factor
I_E = Occupancy Importance Factor
T = Fundamental / Natural Period of Structure